DECLARATION

I, Toshio TAKAMATSU, a citizen of Japan, c/o Miyoshi & Miyoshi of Toranomon Daiichi Bldg., 2-3, Toranomon 1-chome, Minato-ku, Tokyo 105-0001, Japan, do hereby solemnly and sincerely declare:

That I am well acquainted with the Japanese language and English language; and

That the attached is a true and faithful translation made by me of the Japanese document, namely Japanese Patent Application No. 2001-048756 to the best of my knowledge and belief.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further, that these statements were made with knowledge that willful false statements and the like so made are punishable by fine or imprisonment or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the above-captioned application or any patent issuing therefrom.

This 11th day of August, 2003

Toshio TAKAMATSU

JAPAN PATENT OFFICE

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[Name of Document] SPECIFICATION

[Title of the Invention] LASER WELD QUALITY MONITORING METHOD AND SYSTEM

[Claim for a Patent]

[Claim 1] A laser weld quality monitoring method, comprising the steps of:

detecting reflected lights from a welding part of laser beams irradiated toward the welding part of a workpiece;

calculating a frequency distribution of a signal obtained from the detected reflected lights;

calculating a signal intensity in a specified frequency band among the calculated frequency distribution; and

if the calculated signal intensity exceeds a preset reference value, determining that an occurrence of porosity is excessive, and if not exceeding the reference value, determining that an occurrence of porosity is within a normal range.

[Claim 2] A laser weld quality monitoring method, comprising the steps of:

detecting reflected lights from a welding part of laser beams irradiated toward the welding part of a workpiece;

converting the detected reflected light to an electric signal;

calculating a frequency distribution of the converted electric signal;

calculating a signal intensity in a specified frequency band among the calculated frequency distribution; and

if the calculated signal intensity exceeds a preset reference value, determining that an occurrence of porosity is excessive, and if not exceeding the reference value, determining that an occurrence of porosity is within a normal range.

[Claim 3] A laser weld quality monitoring method according to claim 1 or 2, wherein a specified frequency band for calculating the signal intensity is varied in correspondence to a plate thickness of a workpiece.

[Claim 4] A laser weld quality monitoring method according to any one of claims 1 to 3, wherein the calculation of the signal intensity is carried out by using a fast Fourrier transform (FFT) for calculating a frequency distribution of the signal intensity or a band filter for passing a signal of only the specified frequency band.

[Claim 5] A laser weld quality monitoring method according to any one of claims 1 to 4, wherein the workpiece is a steel sheet plated with zinc.

[Claim 6] A laser weld quality monitoring system, comprising:

a reflected light detecting means for detecting reflected lights from a welding part of laser beams irradiated toward the welding part of a workpiece;

an electric signal converting means for converting the detected reflected light to an electric signal;

a frequency distribution calculating means for calculating a frequency distribution of the converted electric signal;

a signal intensity calculating means for calculating a signal intensity in a specified frequency band among the calculated frequency distribution; and

a weld quality determining means for, if the calculated signal intensity exceeds a preset reference value, determining that an occurrence of porosity is excessive, and if not exceeding the reference value, determining that an occurrence of porosity is within a normal range.

[Claim 7] A laser weld quality monitoring system according to claim 6, wherein the reflected light detecting means has an interference filter for passing only lights of a wavelength of laser beams in order to detect only the reflected lights of the laser beams.

[Claim 8] A laser weld quality monitoring system according to claim 6, wherein the signal intensity calculating means calculates a signal intensity of an electric signal by using a fast Fourier transform (FFT) for calculating a frequency distribution of the signal intensity or a band filter for passing a signal of only the specified frequency band.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to a laser weld quality monitoring method and system. In particular, the invention relates to a laser weld quality monitoring method and system adapted to monitor an occurrence of a porocity in a laser welding part.

[0002]

[Prior Art]

The welding of very thin steel sheets, such as for a vehicle body, is performed by a laser welding. In comparison with a spot welding, the laser welding has many advantages such that it is applicable to a one-side welding without the need of clamping steel sheets from both obverse and reverse, and that it allows an easy welding even at an inside of a complicate narrow groove. However, as a disadvantage, it tends to suffer a

degradation of welding quality caused by a failed lapping accuracy between steel sheets or accrued suddenly at a stained welding part.

[0003]

Therefore, hitherto, the monitoring method of a laser welding part is performed by predicting a weld quality in a real-time manner. Japanese Patent Application Laying-Open Publication No. 2000-271768 has disclosed techniques of using two sensors having their detection angles different from each other, for sensing lights from a plume occurring at a keyhole in the laser welding part and reflected lights of a YAG (Yttrium Aluminum Garnet) laser radiated, to detect variations of output, focal position, and inter-sheet gap as welding conditions by intensities of light detected by each sensor, thereby performing a real-time prediction of a quality of the laser welding part.

[0004]

[Problems to be Solved by the Invention]

However, in a conventional weld quality monitoring method, it is possible to detect an occurrence of a defective quality (an under-filled state) that a laser welding part is grooved, and an occurrence of a defective welding condition which is deviated from a prescribed welding condition, but there arises a problem that it is difficult to detect an occurrence of porosity (a porous state) of the welding part, occurred during laser welding in a zinc-plated steel sheet, or the like.

[0005]

The difficulty in detection of an occurrence of porous state in the conventional weld quality monitoring method

resides in that a decision on quality is made of a state of weld based on light emitted from a region (keyhole) irradiated and melted by a laser beam. The reason is that the porous state is caused by a mixing of zinc vapor inside the keyhole, which mixing of zinc vapor seldom imparts variations in the light emitted from the keyhole.

[0006]

The present invention has been invented with such conventional problems in mind, and it is an object of the present invention to provide a laser weld quality monitoring method capable of reliably detecting an occurrence of porosity of a laser welding part.

[0007]

[Means for Solving the Problems]

In order to solve the above-described problems and attain the object, the laser weld quality monitoring method according to a first feature of the present invention comprises the steps of: detecting reflected lights from a welding part of laser beams irradiated toward the welding part of a workpiece; calculating a frequency distribution of a signal obtained from the detected reflected lights; calculating a signal intensity in a specified frequency band among the calculated frequency distribution; and if the calculated signal intensity exceeds a preset reference value, determining that an occurrence of porosity is excessive, and if not exceeding the reference value, determining that an occurrence of porosity is within a normal range.

[0008]

According to the first feature of the present invention,

as only signals of the specified frequency band which are necessary for detecting an occurrence of excessive porosity are extracted from the signals produced based on reflected lights of laser beams, it is possible to determine based on the signal intensity of the extracted signals to what extent porocity occurred. Accordingly, it is possible to reliably detect an occurrence of excessive porocity that was difficult to detect conventionally.

[0009]

The laser weld quality monitoring method according to a second feature of the present invention comprises the steps of: detecting reflected lights from a welding part of laser beams irradiated toward the welding part of a workpiece; converting the detected reflected light to an electric signal; calculating a frequency distribution of the converted electric signal; calculating a signal intensity in a specified frequency band among the calculated frequency distribution; and if the calculated signal intensity exceeds a preset reference value, determining that an occurrence of porosity is excessive, and if not exceeding the reference value, determining that an occurrence of porosity is within a normal range.

[0010]

According to the second feature of the present invention, as only electric signals of the specified frequency band which are necessary for detecting an occurrence of excessive porosity are extracted from the electric signals produced based on reflected lights of laser beams, it is possible to determine based on the signal intensity of the extracted electric signals to what extent porocity occurred. Accordingly, it is possible to reliably detect an occurrence of excessive porocity that it was difficult to detect conventionally.

[0011]

In the laser weld quality monitoring method according to a third feature of the present invention, in the laser weld quality monitoring method according to claim 1 or 2, a specified frequency band for calculating the signal intensity is varied in correspondence to a plate thickness of a workpiece.

[0012]

According to the third feature of the present invention, a specified frequency band for calculating the signal intensity varies in correspondence to a plate thickness of a workpiece. Accordingly, variations of accuracy in detecting an occurrence of porocity due to a difference in the plate thickness are dissolved.

[0013]

In the laser weld quality monitoring method according to a fourth feature of the present invention, in the laser weld quality monitoring method according to any one of claims 1 to 3, the calculation of the signal intensity is carried out by using a fast Fourier transform (FFT) for calculating a frequency distribution of the signal intensity or a band filter for passing a signal of only the specified frequency band.

[0014]

According to the fourth feature of the present invention, signals of a specified frequency band which are easy to detect a state of an occurrence of porocity are extracted by using a fast Fourier transform (FFT) for calculating a frequency distribution of the signal intensity or a band filter for passing a signal of only the specified frequency band. Accordingly, it is possible to reliably detect an occurrence

of excessive porosity that it was difficult to detect conventionally.

[0015]

In the laser weld quality monitoring method according to a fifth feature of the present invention, in the laser weld quality monitoring method according to any one of claims 1 to 4, the workpiece is a zinc-plated steel sheet.

[0016]

The laser weld quality monitoring system according to a sixth feature of the present invention comprises: a reflected light detecting means for detecting reflected lights from a welding part of laser beams irradiated toward the welding part of a workpiece; an electric signal converting means for converting the detected reflected light to an electric signal; a frequency distribution calculating means for calculating a frequency distribution of the converted electric signal; a signal intensity calculating means for calculating a signal intensity in a specified frequency band among the calculated frequency distribution; and a weld quality determining means for, if the calculated signal intensity exceeds a preset reference value, determining that an occurrence of porosity is excessive, and if not exceeding the reference value, determining that an occurrence of porosity is within a normal range.

[0017]

According to the sixth feature of the present invention, as only electric signals of the specified frequency band which are necessary for detecting an occurrence of excessive porosity are extracted from the electric signals produced based on reflected lights of laser beams by the frequency distribution

calculating means, the weld quality determining means can determine based on the signal intensity of the extracted electric signals to what extent porocity occurred. Accordingly, it is possible to reliably detect an occurrence of excessive porocity that it was difficult to detect conventionally.

[0018]

In the laser weld quality monitoring method according to a seventh feature of the present invention, in the laser weld quality monitoring system according to claim 6, the reflected light detecting means has an interference filter for passing only lights of a wavelength of laser beams in order to detect only the reflected lights of the laser beams.

[0019]

According to the seventh feature of the present invention, as only reflected lights of laser beams can be detected by the interference filter, detection accuracy of an occurrence of porocity is raised.

[0020]

In the laser weld quality monitoring method according to an eighth feature of the present invention, in the laser weld quality monitoring system according to claim 6, the signal intensity calculating means calculates a signal intensity of an electric signal by using a fast Fourier transform (FFT) for calculating a frequency distribution of the signal intensity or a band filter for passing a signal of only the specified frequency band.

[0021]

According to the eighth feature of the present invention, signals of a specified frequency band which are easy to detect a state of an occurrence of porocity are extracted by using a fast Fourrier transform (FFT) for calculating a frequency distribution of the signal intensity or a band filter for passing a signal of only the specified frequency band. Accordingly, it is possible to reliably detect an occurrence of excessive porocity that it was difficult to detect conventionally.

[0022]

[Effect of the Invention]

As described above, according to the first, second or fifth feature of the present invention, signals of the specified frequency band which can easily detect an occurrence of excessive porosity based on reflected lights of laser beams are extracted. Therefore, it is possible to reliably detect an occurrence of excessive porocity that it was difficult to detect conventionally.

[0023]

According to the third feature of the present invention, as a specified frequency band for calculating the signal intensity varies in correspondence to a plate thickness of a workpiece, variations of accuracy in detecting an occurrence of porocity due to a difference in the plate thickness can be dissolved.

[0024]

According to the fourth feature of the present invention, signals of a specified frequency band which are easy to detect a state of an occurrence of porocity are extracted by using a

fast Fourier transform (FFT) for calculating a frequency distribution of the signal intensity or a band filter for passing a signal of only the specified frequency band so that an occurrence of excessive porocity can be detected based on reflected lights of laser beams. Accordingly, it becomes possible to reliably detect an occurrence of excessive porocity that it was difficult to detect conventionally.

[0025]

According to the sixth feature of the present invention, as signals of the specified frequency band which can easily detect an occurrence of excessive porosity based on reflected lights of laser beams are extracted, it is possible to reliably detect an occurrence of excessive porocity that it was difficult to detect conventionally.

[0026]

According to the seventh feature of the present invention, as only reflected lights of laser beams can be detected by the interference filter, detection accuracy of an occurrence of porocity can be raised.

[0027]

According to the eighth feature of the present invention, only signals of a frequency band which are easy to detect a state of an occurrence of porocity are extracted by using a fast Fourrier transform (FFT) for calculating a frequency distribution of the signal intensity or a band filter for passing a signal of only the specified frequency band. Accordingly, it is possible to reliably detect an occurrence of excessive porocity that it was difficult to detect conventionally.

[0028]

[Preferred Embodiment]

Hereinafter, a laser weld quality monitoring method and system according to a preferred embodiment of the present invention will be in detail described with reference to the accompanying drawings, by exemplifying a case where a welding member is a zinc-plated steel sheet. Fig. 1 is an embodied structural diagram of a YAG laser welder equipped with a quality monitoring system according to the present invention.

[0029]

An optical fiber cable 2 is attached to an upper part of a YAG laser welder 100, and laser beams from a YAG laser oscillator (not shown) are led to the YAG laser welder 100 by the optical fiber cable 2. A light converging optical system for converging the led laser beams is disposed ranging from a center part to a lower part of the YAG laser welder 100. The light converging optical system has a collimator lens 3 and a light converging lens 4, and after the led laser beams are changed to parallel lights by the collimator lens 3, the led laser beams are converged on a surface of a workpiece (vehicle body panel) 5 by the light converging lens 4. The light converged part (welding part) is melted by energy of laser beams, so that the workpieces are welded to each other.

[0030]

Further, in a lower surface of the YAG laser welder 100, a sensor 6a which functions as a reflected light detecting means is disposed at a location of an angle of elevation 60 degrees ($\theta 1$) from a surface of the workpiece 5 and a sensor 6b is disposed at a location of an angle of elevation 10 degrees ($\theta 2$) from a surface of the workpiece 5. The sensor 6a is a sensor for

detecting reflected lights of laser beams reflected without being absorbed by the workpiece 5 after irradiated mainly by the welding part. The sensor 6b is a sensor for detecting plasmatic lights (visible lights) produced from the welding part during welding. A weld quality of the welding part is determined in real time based on lights (reflected lights and plasmatic lights) detected by both the sensors 6a and 6b. As the monitoring method and the monitoring system according to the present invention detect an occurrence of porocity by use of reflected lights of laser beams, the sensor 6a is a particularly important sensor.

[0031]

Fig. 2 is a conceptual diagram of the YAG laser welder equipped with the quality monitoring system according to the present invention. The YAG laser welder shown in Fig. 2 comprises a YAG laser oscillator 1, and laser beams produced by the YAG laser oscillator 1 are led to a light converging optical system by the optical fiber cable 2, and are changed to parallel lights by the collimator lens 3. Thereafter, lights are converged on a surface of the workpiece 5 by the light converging lens 4, to weld the workpiece 5 by power of the converged laser beams.

[0032]

On the other hand, the sensor 6a is disposed at a first location where the angle of elevation $\theta 1$ is 60° from the surface of the workpiece 5, and reflected lights of a YAG laser reflected without being absorbed by the workpiece 5 after irradiated on a welding part F are converted into an electric signal in correspondence to an intensity thereof by the sensor 6a. Accordingly, the sensor 6a functions as an electric signal converting means. Further, the sensor 6b is disposed at a second location where the angle of elevation $\theta 2$ is 10° from the

surface of the workpiece 5, and plasmatic lights (visible lights) from a plume (metallic vapor at high temperatures) produced in the welding part F during welding are converted into an electric signal in correspondence to an intensity thereof by the sensor 6b. The electric signal converted by both the sensors 6a and 6b are input to a measuring device 7 constituted by an amplifier (preamp), a band-pass filter, an A/D converter, a personal computer, or the like.

[0033]

As shown in Fig. 3, the sensors 6a and 6b comprises two photodiodes 8 and 9, a dichroic mirror 10, and an interference filter 11 which transmits only a wavelength of 1064 nm ± 10 nm.

[0034]

In the sensors 6a and 6b, first, lights from the welding part entered from a left side of Fig. 3 are selected in correspondence to a wavelength by the dichroic mirror 10. Namely, a visible light of wavelength 500 nm or less is reflected by the dichroic mirror 10 and led to the photodiode 8, and the visible light is converted into an electric signal as a plasmatic light, to detect an intensity thereof. On the other hand, after an infrared light out of an incident light from the welding part transmits the dichroic mirror 10, only a YAG laser beam having wavelength 1.06μm transmits the interference filter 11. The YAG laser beams are led by the photodiode 9, and converted into an electric signal as YAG reflected lights, and input into the measuring device 7, respectively. As the monitoring device and the monitoring system according to the present invention detect an occurrence of porocity by use of reflected lights of laser beams, the electric signal from the photodiode 9 provided in the sensor 6a is used.

[0035]

Fig. 4 is a diagram showing an embodied constitution of the measuring device 7 shown in Fig. 2. The measuring device 7 is provided corresponding to each of the photodiodes 8 and 9 provided in each of the sensors 6a and 6b. Accordingly, the monitoring device of the present invention is provided with the four measuring devices 7. A constitution of each measuring device 7 is identical.

[0036]

The measuring device 7 comprises an amplifier (preamp) 7A for amplifying an electric signal from the photodiode 9 to a constant level; A/D converters 7B and 7D for converting an analog electric signal output from the amplifier 7A into a digital electric signal; a band-pass filter 7C for passing only the electric signal of a specified frequency band; a personal computer 7E which functions as a frequency distribution calculating means for calculating a frequency distribution of the input electric signal, functions as a signal intensity calculating means for calculating a signal intensity in the specified frequency band, and functions as a weld quality determining means for determining a condition of an occurrence of porocity; and a display 7F for displaying a result obtained by determining a weld quality.

[0037]

Figs. 5 to 7 are views for explaining a principle of detecting a weld quality. The reason that the weld quality can be detected by analyzing lights from the welding part will be described with reference to Figs. 5 to 7. Figs. 5 and 6 show a condition of an occurrence of porocity when a zinc-plated steel sheet as an object to be welded is lap-welded. As shown in Fig. 5, when the YAG laser welder 100 irradiates YAG laser beams of high power density on a butt part 20 of the zinc-plated

steel sheet, the irradiated part (welding part) starts melting by receiving energy of laser beams, to form a keyhole 25 in which a metal is melted. At this time, a zinc-plated layer 21 plated on a surface of a steel sheet is varied to a metallic vapor at a melting temperature of a steel 22 as a base metal. Bubble-like porocity (blowhole) 23 occurs in the keyhole 25 by pressure of the metallic vapor.

[0038]

As shown in Fig. 6, laser beams are absorbed by a wall 26 on a front surface of the keyhole 25. In lap-welding of the zinc-plate steel sheet, when the zinc-plated layer 21 existing on an interface of two steel sheets, a zinc metallic vapor 27 jets into the keyhole 25. This becomes the porocity 23. In welding with the YAG laser beams, as a wavelength of laser beams is short at 1.06μm or thereabout, laser beams are almost transparent with respect to a plume 28 jetted from an opening part of the keyhole 25. Accordingly, the high-speed phenomenon as to presence or absence of the porocity 23 cannot be caught by observation of the plume 28.

[0039]

However, it is considered that reflected lights of the YAG laser beams are changed by a state of the wall 26 on the front surface of the keyhole 25. When a state of the wall 26 on the front surface of the keyhole 25 varies with jetting of the zinc metallic vapor 27, the reflected lights of laser beams varies correspondingly. As this phenomenon occurs inside the keyhole 25 in the vicinity of the interface of the steel sheet, the phenomenon cannot be caught by the sensor 6b that an observation angle is at a low level, but the phenomenon can be caught by the sensor 6a that an observation angle is at a high level. Accordingly, it is necessary to set an angle in installing the sensor 6a within the range of an angle that a

variation state of the wall 26 on the front surface of the keyhole 25 can be caught by the reflected lights. Actually, the angle is in the range of not interfacing with laser beams irradiated on the welding part and of being capable of catching the variation state of the wall 26 on the front surface of the keyhole 25 by the reflected lights, namely in the range of an angle of elevation 45 degrees to 70 degrees. It is to be noted that a further optimum angle within the range of this angle is decided in correspondence to a welding condition such as a plate thickness, power of laser beams, or the like. In this embodiment, as shown in Fig. 1, the angle of elevation is 60 degrees.

[0040]

Further, as shown in Fig. 7, when the zinc-plated steel sheets do not come into appropriate contact with each other in the butt part 20 and a slight gap 30 is caused, a metal melted in the keyhole 25 flows into the gap 30. Therefore, a defective welding which is called an under-filled state 31 occurs. The occurrence of the under-filled state 31 can be caught by the sensor 6b at a low level of the observation angle.

[0041]

Next, a processing for detecting porocity by the monitoring system of the present invention will be described with reference to a flowchart of Fig. 8 and Figs. 9 to 12. Data such as a waveform, etc. shown in Figs. 9 to 12 are obtained as a result of measurement based on a following welding condition (basic welding condition).

[0042]

The YAG laser which outputs at 3 Kw was used. Welding speed is 4.5 m/min. The zinc-plated steel sheet having

thickness 0.8 mm was used.

[0043]

A flowchart of Fig. 8 shows a procedure of the monitoring method of the present invention. When the YAG laser beams are irradiated on the butt part 20 of the zinc-plated steel sheet, the irradiated part is melted by receiving energy of laser beams. As the melted metal is at a very high temperature, visible lights, infrared lights, reflected lights of YAG laser beams, or the like are radially released from the keyhole 25 and the plume 28. The sensors 6a and 6b enter these lights and convert the lights into an electric signal. The converted electric signal is stored in a waveform storage device (not shown) of the personal computer 7E (refer to Fig. 4) (S1).

[0044]

Fig. 9 is a waveform chart (converted by the photodiode 9) of an electric signal obtained from reflected lights of the YAG laser lights during welding under a basic welding condition. The waveform chart of this electric signal is prepared at sampling frequency 20KHz. In this waveform chart, a y-axis represents a signal intensity and an x-axis represents a time. Further, YH denotes a temporal variation condition of reflected lights caught by the sensor 6a at a high level of the observation angle. YL denotes a temporal variation condition of reflected lights caught by the sensor 6b at a low level of the observation angle. This chart shows waveforms of a "non-defective product" normally welded, a "porocity product" in which an occurrence of porocity is excessive, and an "under-filled product" in which an under-filled state is caused. In case of the under-filled product, a shape of waveforms apparently differs from a case of a non-defective product. Therefore, it is easy to determine as the under-filled product. However, as in case of the porocity product, a difference in the shape of waveforms is not

seen by comparison with a case of the non-defective product, it is difficult to determine as the porocity product.

[0045]

Fig. 10 is a waveform chart (converted by the photodiode 8) of an electric signal obtained from visible lights of the keyhole 25 and the plume 26 during welding under a basic welding condition. The waveform chart is also prepared at sampling frequency 20KHz. In this waveform chart, a y-axis represents a signal intensity and an x-axis represents a time. Further, YH denotes a temporal variation condition of visible lights caught by the sensor 6a at a high level of the observation angle. YL denotes a temporal variation condition of visible lights caught by the sensor 6b at a low level of the observation angle. This chart shows waveforms of a "non-defective product" normally welded, a "porocity product" in which an occurrence of porocity is excessive, and an "under-filled product" in which an under-filled state is caused. In case of the under-filled product, a shape of waveforms apparently differs from a case of a non-defective product. Therefore, it is easy to determine as the under-filled product. However, as in case of the porocity product, a difference in the shape of waveforms is not seen by comparison with a case of the non-defective product, it is difficult to determine as the porocity product.

[0046]

In this manner, it is difficult to differentiate between the non-defective product and the porocity product only by examining a temporal intensity change state of each of the reflected lights and the visible lights by each of the sensors 6a and 6b. For this reason, the waveforms of only the YH indicating the temporal variation condition of reflected lights caught by the sensor 6a at a high level of the observation angle are taken out among the waveforms stored in the waveform storage

device, and this waveform is subjected to a FFT (fast Fourier transform) signal intensity calculation (S2).

[0047]

Fig. 11 is a waveform chart obtained as a result of subjecting the waveform of the YH shown in Fig. 9 to the FFT signal intensity calculation. In this waveform chart, a y-axis represents a relative signal intensity and an x-axis represents a frequency. As is apparent from this chart, if the FFT signal intensity calculation is carried out, a difference in a distribution of the relative signal intensity is caused between the non-defective product and the porocity product. In other words, in the non-defective product, a peak part of the relative signal intensity exists in the vicinity of 100 Hz to 500 Hz, but in the porocity product, a peak part of the relative signal intensity exists in the vicinity of 500 Hz to 1000 Hz. The quality monitoring method of the present invention differentiates this difference as follows:

[0048]

Among the waveform of Fig. 11 obtained as a result of subjecting the FFT (fast Fourier transform) signal intensity calculation, the total value of the signal intensity between 605 Hz and 650 Hz is calculated (S3). If the total value exceeds 170,000 set as a reference value (S4, Yes), it is determined that an occurrence of porocity is excessive (S5), and if not exceeding 170,000 (S4, No), it is determined that an occurrence of porocity is within the normal range (S6). It is to be noted that a result of determining an occurrence of porocity (not shown in the flowchart) is displayed on the display 7F.

[0049]

Next, from a feature amount of waveforms of Fig. 1 obtained

as a result of subjecting the FFT (fast Fourier transform) signal intensity calculation, a Maharanobis distance is calculated (S7). This Maharanobis distance represents by a distance to what extent a feature amount (location) of a waveform of the observed workpiece is away from a normalized reference space obtained from a feature amount of waveforms of a non-defective product. According to the acquired Maharanobis distance, a distribution chart as shown in Fig. 12 is prepared. For example, as shown in Fig. 12, the feature amount (location) obtained from the waveform chart of Fig. 11 is written in a graph that a y-axis is a FFT signal intensity and an x-axis is a Maharanobis distance in logarithmic representation, and the products are distributed in correspondence to the feature amount of each workpiece.

[0050]

If the Maharanobis distance exceeds a reference value 1000 based on this distribution chart (S8, Yes), it is determined that an under-filled state occurs (S9), and if not exceeding that (S8, No), it is determined that the under-filled state does not occur (S10).

[0051]

In the above embodiment, whether or not an occurrence of porocity is excessive was determined based on a total value of a signal intensity of a specified frequency band, but as is apparent from the distribution chart of Fig. 12, the porocity products are distributed in a region that the Maharanobis distance is 2 or less and the signal intensity is 170000 or more, and similarly to a case where an occurrence of the under-filled product is determined, from the feature amount of waveforms of Fig. 11 obtained as a result of subjecting the FFT (fast Fourier transform) signal intensity calculation, the Maharanobis distance and the signal intensity of the specified frequency

band are calculated, and further it is determined to which region the distance and signal intensity belong, so that it can be determined whether or not an occurrence of porosity is excessive.

[0052]

Incidentally, in the above embodiment, a description was given on a case that a plate thickness is 0.8 mm, but the quality monitoring method and the quality monitoring system of the present invention can be applied to the other plate thickness. For example, the present invention can be applied to welding of a steel sheet of a plate thickness of 0.7 mm to about 1.2 mm which is used as a panel of a vehicle body of an automobile. In this case, it is necessary that the specified frequency band for calculating the signal intensity is varied corresponding to the plate thickness so that weld quality can be determined appropriately. For example, if the plate thickness is 0.7 mm, a frequency band of 500 Hz to 600 Hz is selected as the specified frequency band for calculating the signal intensity, and if the plate thickness is 1.2 mm, a frequency band of 800 Hz to 1200 Hz is selected as the specified frequency band for calculating the signal intensity, respectively.

[Brief Description of the Drawings]

[Fig. 1]

Fig. 1 is an embodied structural diagram of a YAG laser welder equipped with a quality monitoring system according to the present invention;

[Fig. 2]

Fig. 2 is a conceptual diagram of the YAG laser welder equipped with the quality monitoring system according to the

present invention;

[Fig. 3]

Fig. 3 is a diagram showing an embodied constitution inside a sensor;

[Fig. 4]

Fig. 4 is a diagram showing an embodied constitution of a measuring device shown in Fig. 2;

[Fig. 5]

Fig. 5 is a view for explaining a principle of detecting a weld quality;

[Fig. 6]

Fig. 6 is a view for explaining a principle of detecting the weld quality;

[Fig. 7]

Fig. 7 is a view for explaining a principle of detecting the weld quality;

[Fig. 8]

Fig. 8 is a flowchart showing a procedure of a monitoring method of the present invention;

[Fig. 9]

Fig. 9 is a waveform chart of an electric signal obtained from reflected lights of YAG laser beams during welding under

a basic welding condition;

[Fig. 10]

Fig. 10 is a waveform chart of an electric signal obtained from visible lights of a keyhole and a plume during welding under a basic welding condition;

[Fig. 11]

Fig. 11 is a waveform chart obtained as a result of subjecting a waveform of YH shown in Fig. 9 to a FFT signal intensity calculation; and

[Fig. 12]

Fig. 12 is a distribution chart drawn based on a Maharanobis distance acquired.

[Description of the Reference Numerals]

1: YAG laser oscillator
2: optical fiber cable
3: collimator lens
4: light converging lens
5: workpiece
6a, 6b: sensors
7: measuring device
7A: amplifier
7B, 7D: A/D converters
7C: band-pass filter
7E: personal computer
7F: display
8, 9: photodiodes
10: dichroic mirror
11: interference filter

10: butt part

21: zinc-plated layer

22: steel

23: porocity

25: keyhole

26: wall

27: zinc metallic vapor

28: plume

30: gap

31: under-filled state

100: YAG laser welder

[Name of Document] ABSTRACT

[Abstract]

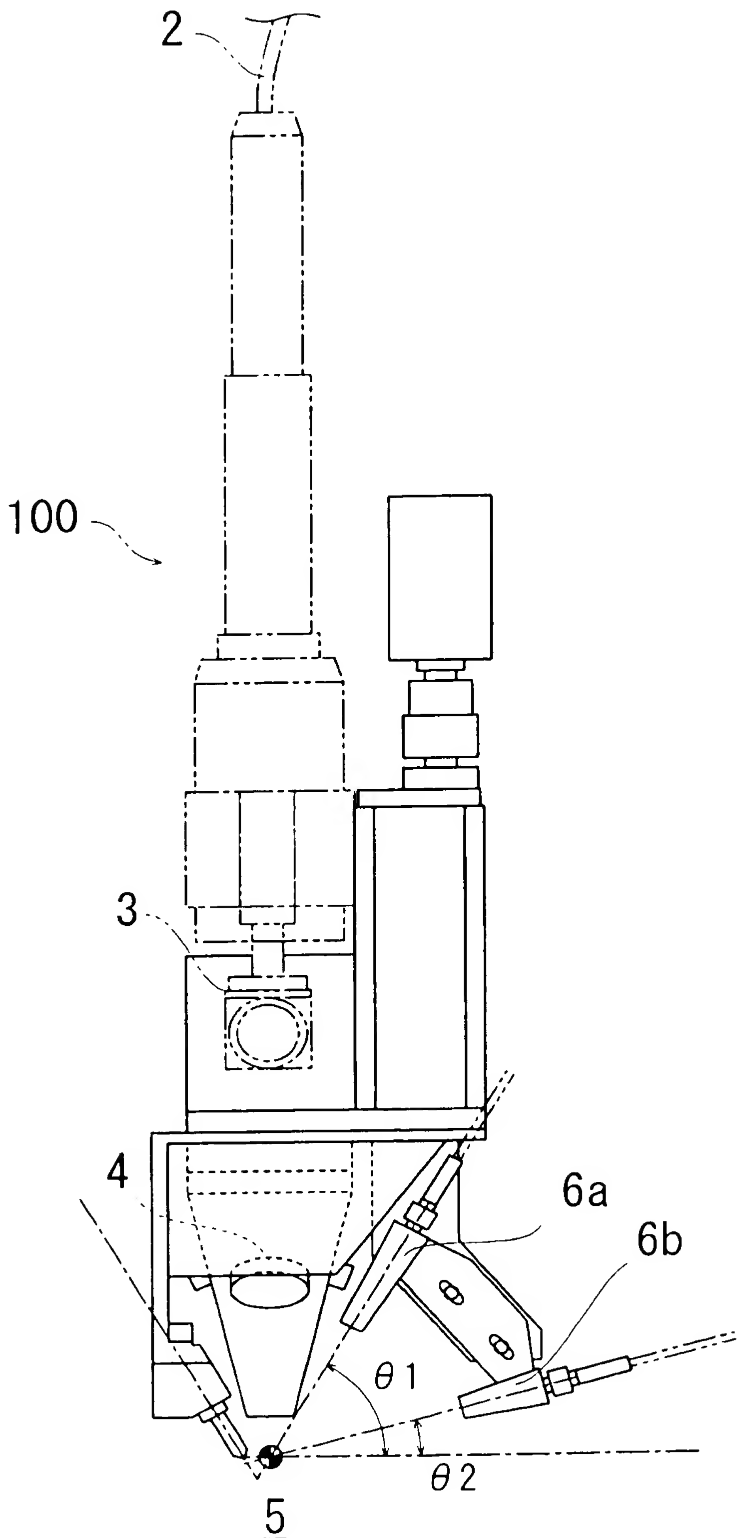
[Object] To detect reliably an occurrence of porocity of a laser welding part.

[Solving Means] Reflected lights of laser beams irradiated toward a welding part F of a workpiece 5 are detected by a sensor 6a and converted into an electric signal, and a measuring device 7 calculates a frequency distribution of the electric signal and calculates a signal intensity in a specified frequency band among the calculated frequency distribution. If the calculated signal intensity exceeds a preset reference value, it is determined that an occurrence of porocity is excessive, and if not exceeding the reference value, it is determined that an occurrence of porocity is within the normal range.

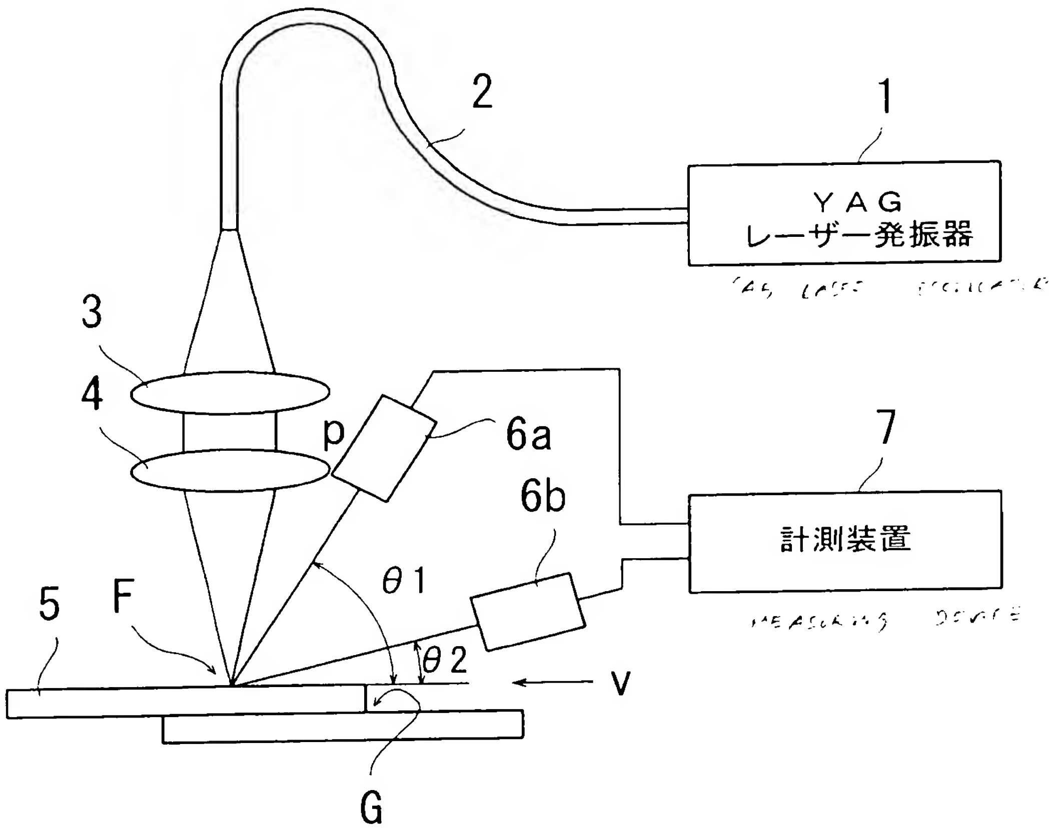
[Selected Figure] Fig. 2

【書類名】　　　　　　図面

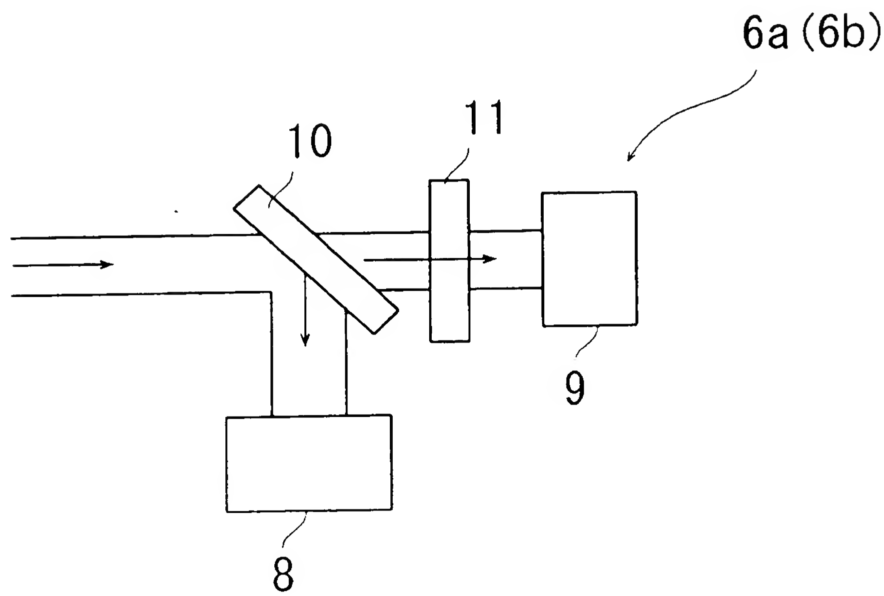
【図１】



【図２】
[Fig. 2]

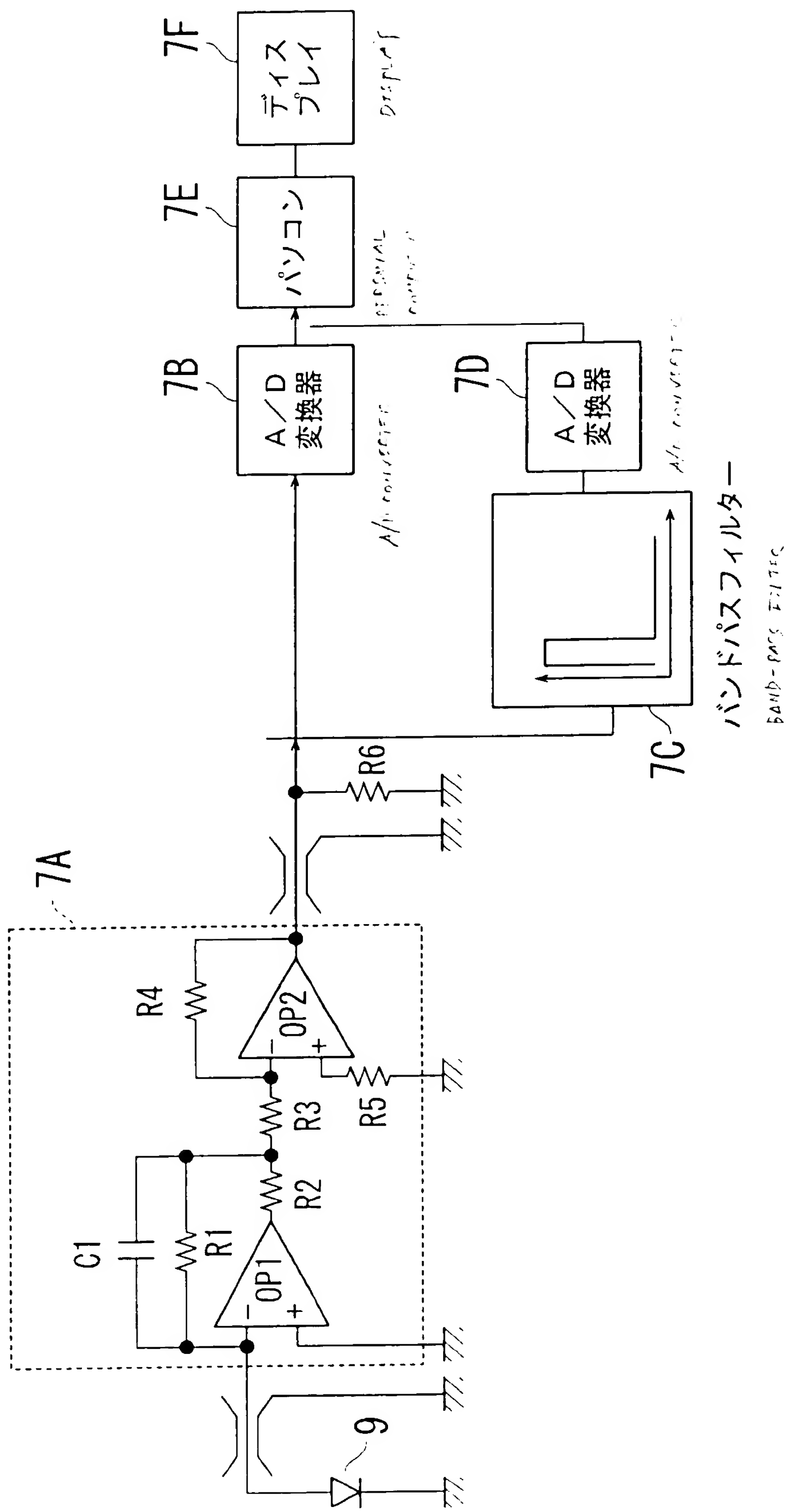


【図３】
[Fig. 3]



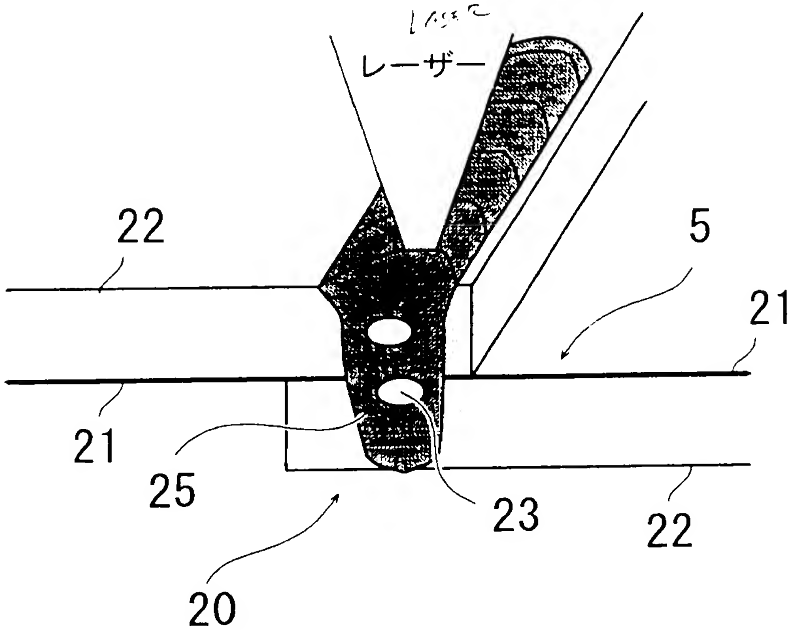
【図４】

[Fig 4]

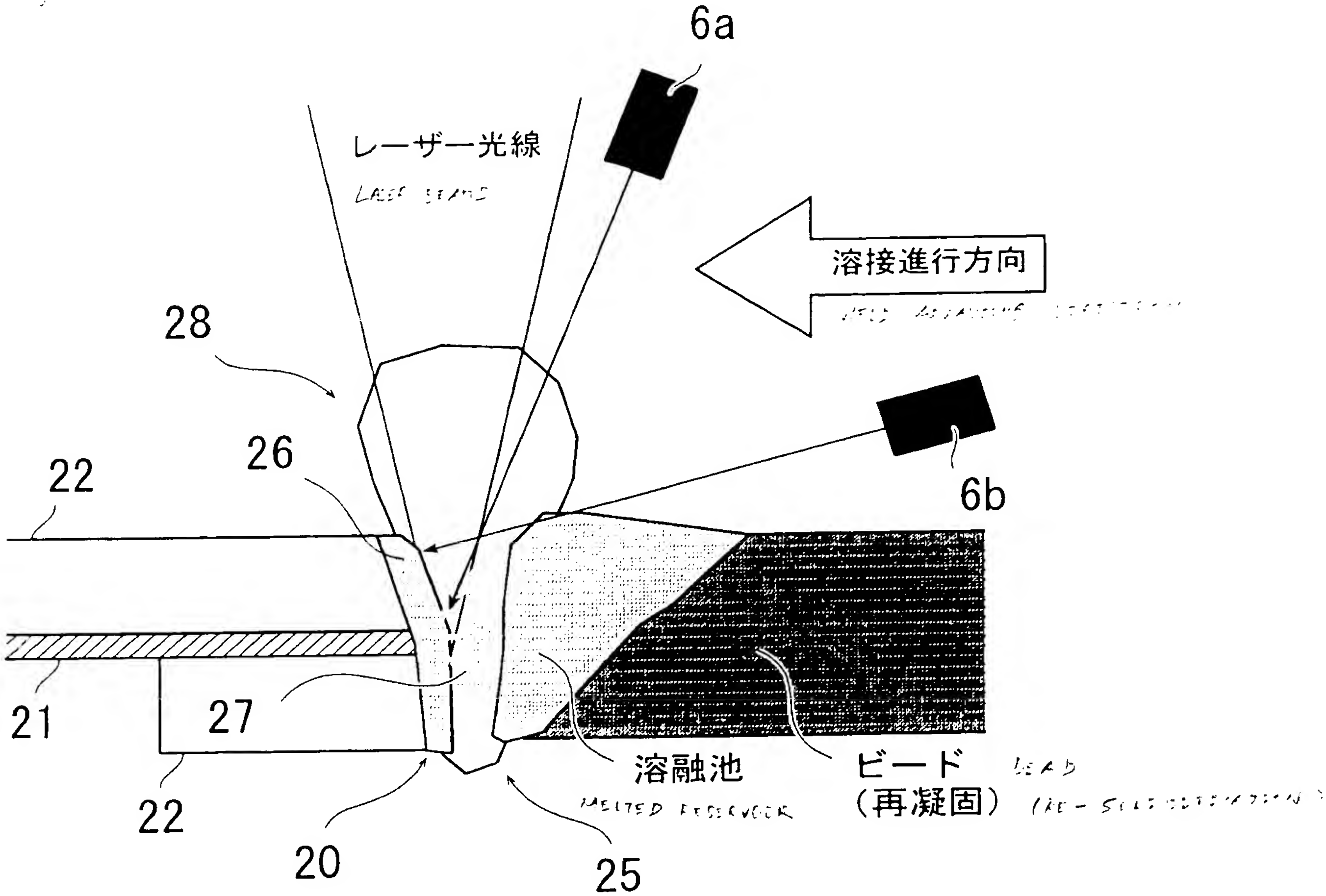

7F
ディスプレイ
7E
パソコン
7B
A／D
変換器
7D
A／D
変換器
7C
バンドパスフィルター
7A
R6
R4
OP2
R3
R5
R2
C1
R1
OP1
9

【図５】

FIG 13



【図６】



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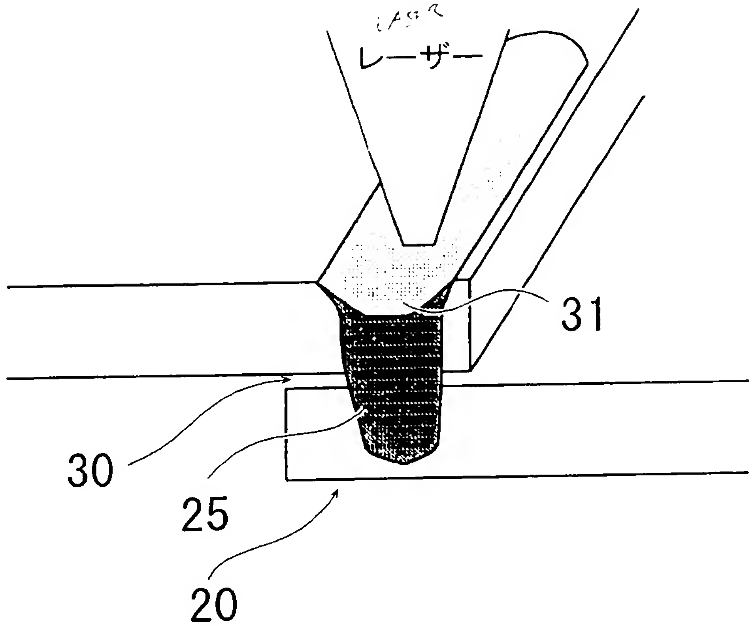
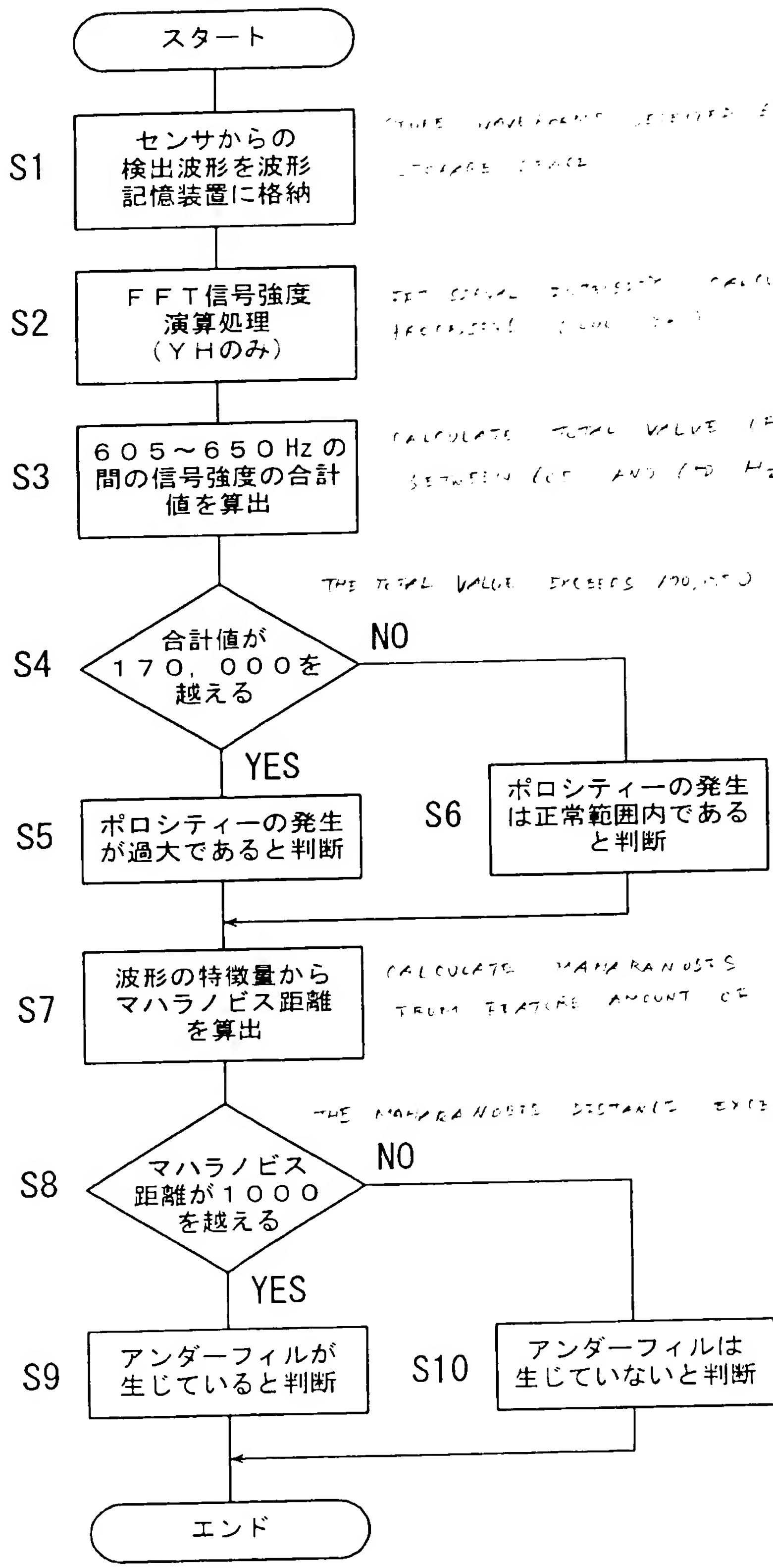
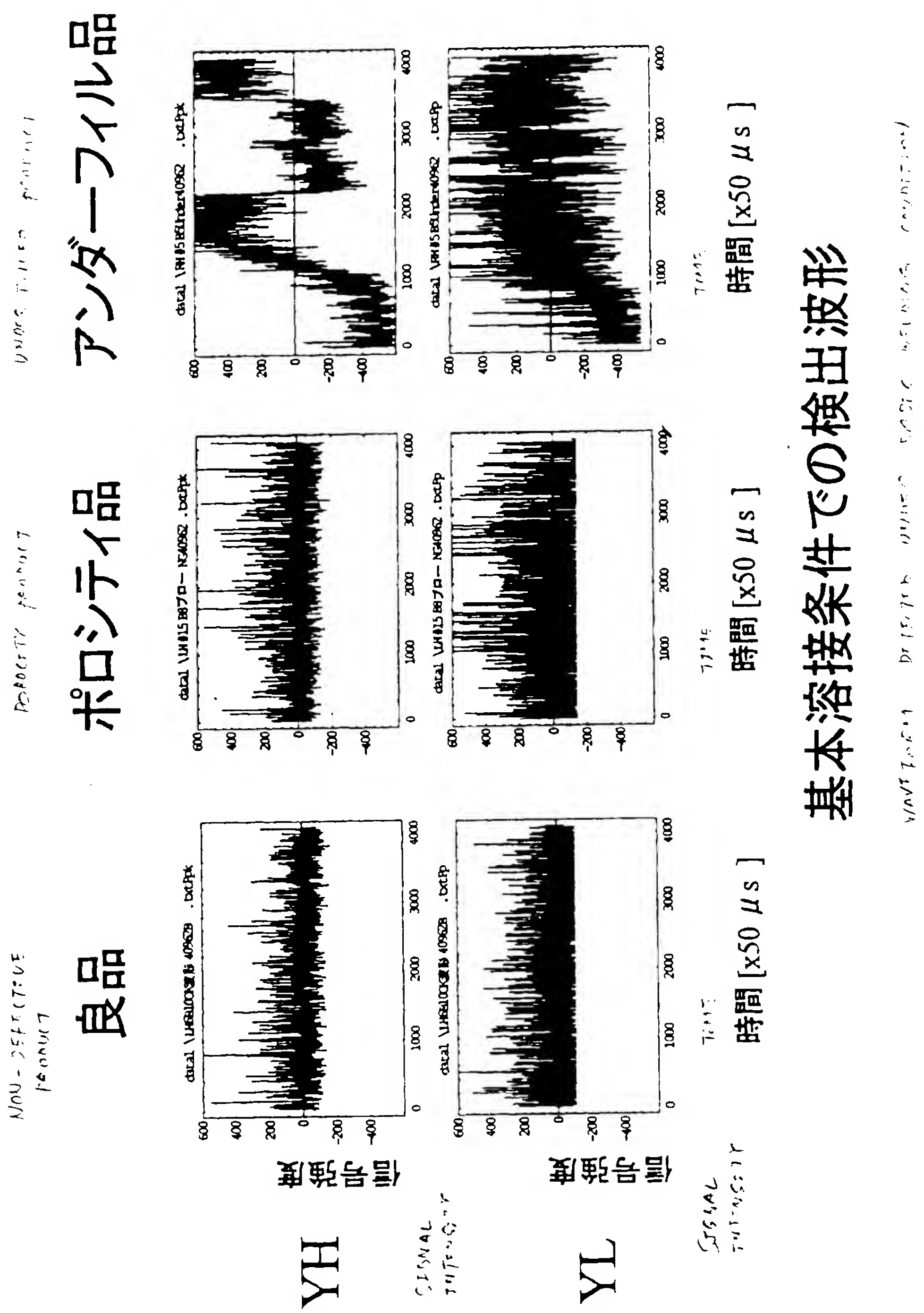


【図８】

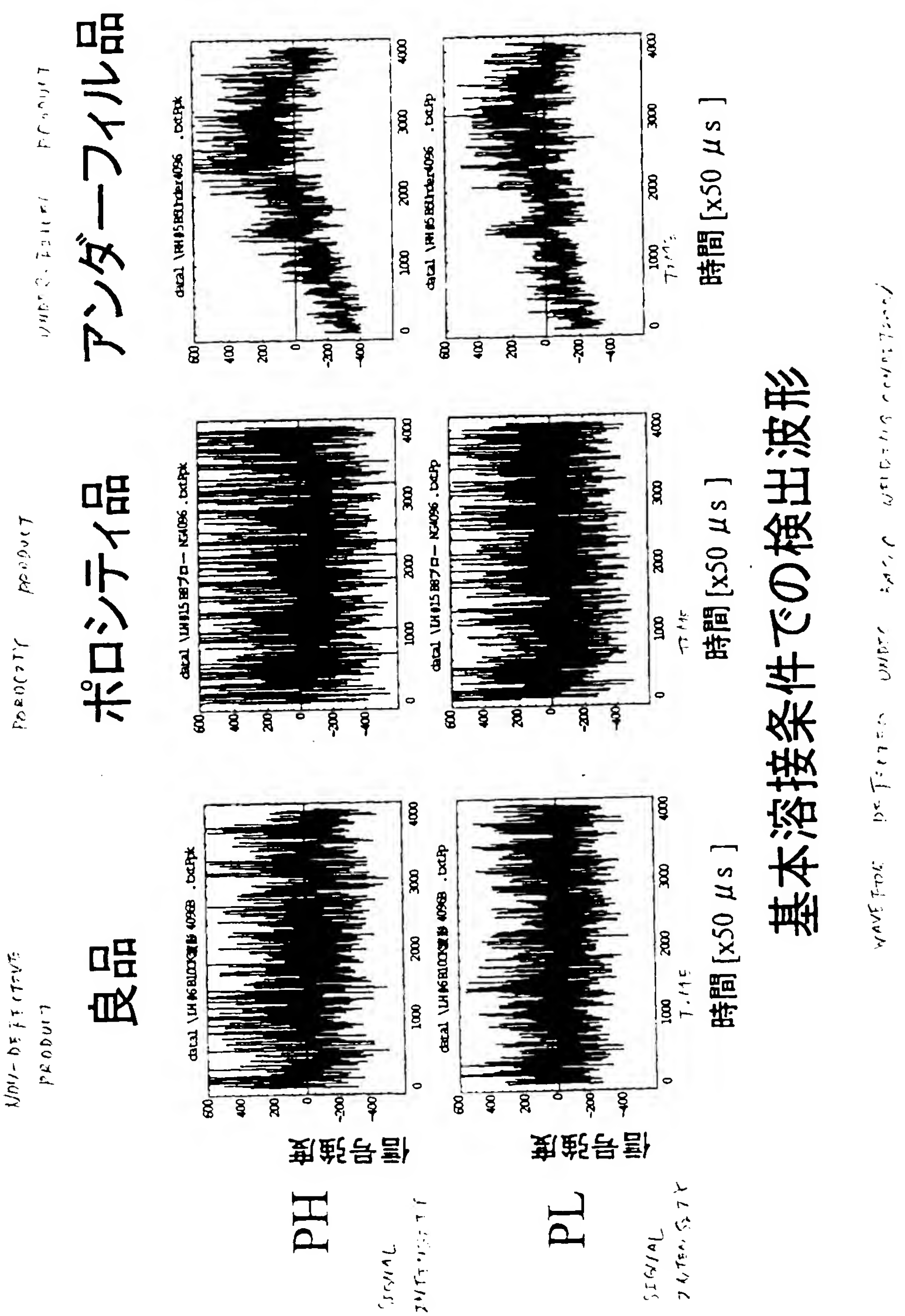

スタート
S1
センサからの検出波形を波形記憶装置に格納
S2
ＦＦＴ信号強度演算処理（ＹＨのみ）
S3
６０５～６５０Hz の間の信号強度の合計値を算出
S4
合計値が１７０，０００を越える
NO
YES
S5
ポロシティーの発生が過大であると判断
S6
ポロシティーの発生は正常範囲内であると判断
S7
波形の特徴量からマハラノビス距離を算出
S8
マハラノビス距離が１０００を越える
NO
YES
S9
アンダーフィルが生じていると判断
S10
アンダーフィルは生じていないと判断
エンド

【図９】



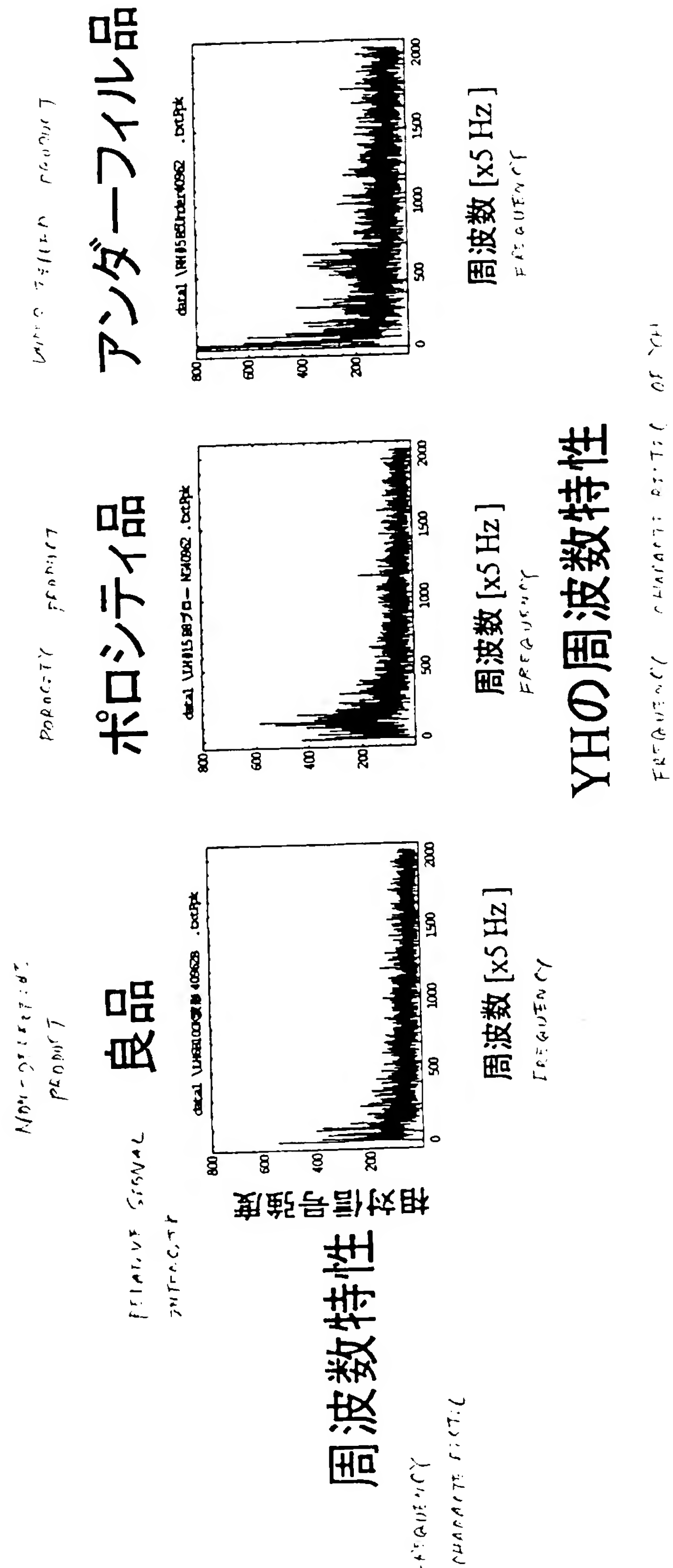
整理番号＝ＮＭ００－０１４０５

【図１０】

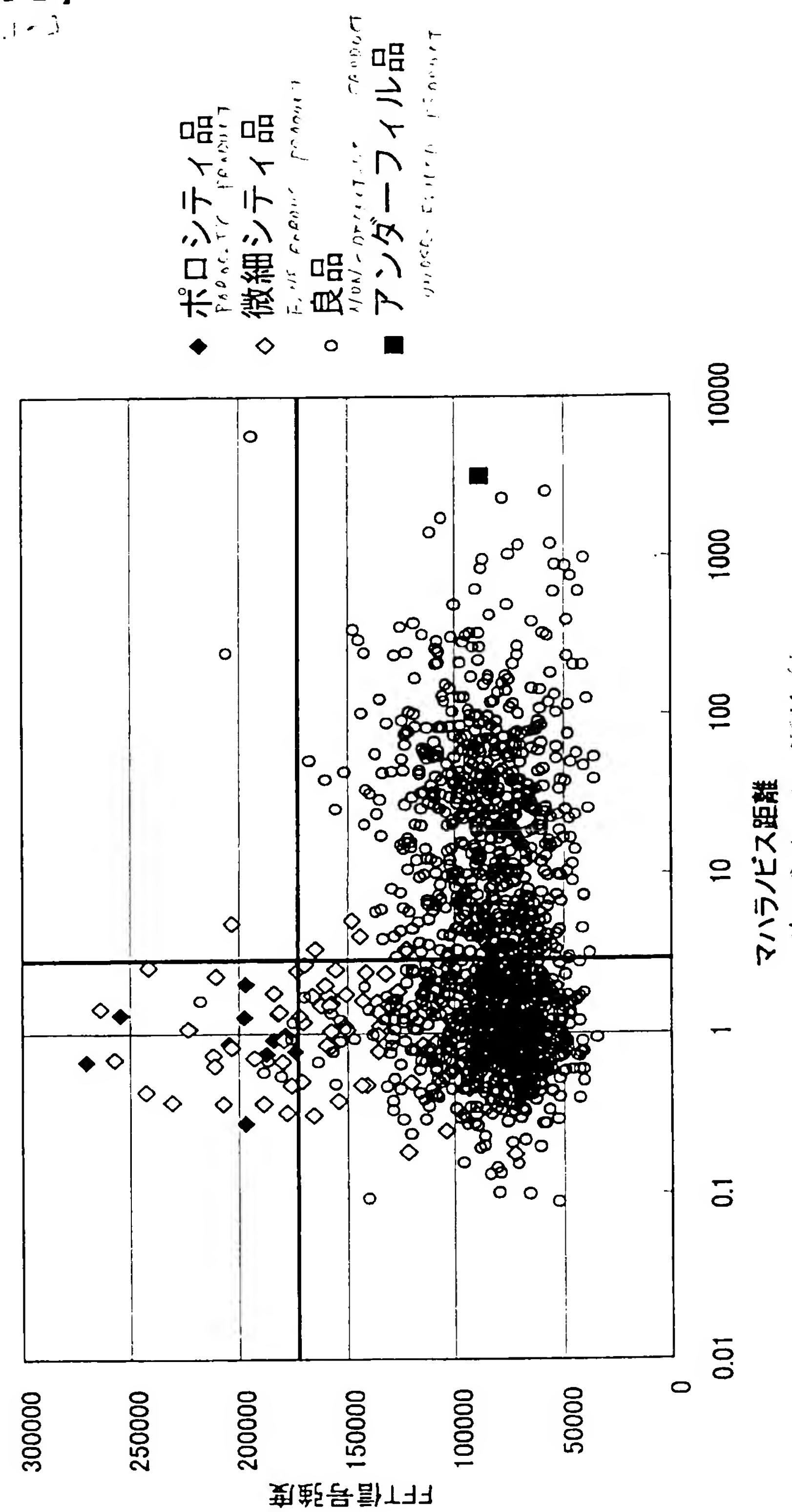


【図11】

FIG 11


周波数特性
FREQUENCY CHARACTERISTIC
相対信号強度
RELATIVE SIGNAL INTENSITY
良品
NON-DEFECTIVE PRODUCT
ポロシティ品
POROSITY PRODUCT
アンダーフィル品
UNDER FILLED PRODUCT
周波数 [x5 Hz]
FREQUENCY
YHの周波数特性
FREQUENCY CHARACTERISTIC OF YH

【図１２】



ポロシティとアンダーフィルの分離結果例